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High rate anaerobic digestion of wastewater separated from grease trap waste

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ABSTRACT

The co-production of biodiesel and methane gas from grease trap waste (GTW) was evaluated and compared against theoretical predictions of methane production from sole anaerobic digestion of GTW. The GTW was first processed into two separate phases comprised of fats, oil, and grease (FOG) and high strength wastewater (GTW wastewater). The GTW wastewater was then anaerobically digested in biochar packed up-flow column reactors to produce methane gas and a low-strength wastewater effluent while the FOG phase was set aside for conversion into biodiesel. Anaerobic digestion efficiencies that yielded chemical oxygen demand (COD) reductions up to 95% and methane headspace concentrations between 60 and 80% were achieved along with FOG to biodiesel conversion efficiencies of 90%. Methane production yields (m^3 per kg COD reduced) achieved theoretical maximums with near total depletion of the volatile organic acids. High resolution images of biochar samples confirmed extensive coverage with thick biofilm communities. Microbial analysis revealed broad spectrum populations of anaerobic bacteria that ferment organic substrates to produce acetate, ethanol, and hydrogen as major end products as well as archaeal populations that produce methane gas. Energy calculations validated the co-production of biodiesel and methane gas from GTW as a competitive option relative to its co-digestion with sewage sludge.

1. Introduction

Grease trap waste (GTW) is a complex aqueous mixture of fats, oils, grease (FOG) and water. GTW has a high chemical oxygen demand (COD) (between 138 and 375 g COD L^{-1} [1–3]), a large fraction of lipids, and yields a dewatered FOG possessing roughly 4.5–6.5 kW h kg^{-1} [4]. Accordingly, dewatered GTW (i.e. FOG) has energy value-added potential for beneficial use in incineration, biodiesel production, or anaerobic co-digestion [4]. The FOG component, however, accounts for only between 0 and 15% by volume of the GTW, with the remaining wastewater still requiring treatment due to its high strength (~15–20 g COD L^{-1}). As such, processes that produce biodiesel from the FOG component of the GTW must also manage a significant wastewater byproduct. More, the FOG phase has a high free fatty acid content, which requires an additional acid catalyzed pretreatment step in addition to the typical alkaline catalyzed transesterification of triglycerides for biodiesel production [4]. For these reasons, there have been numerous publications promoting either the direct anaerobic digestion of GTW or its co-digestion with sewage sludge [5]. Anaerobic digestion is a robust process and is widely applied as a process to recover energy from biomass and waste [6]. Despite the reported benefits of direct co-digestion, these and other studies have also reported a wide assortment of operational challenges, such as the inhibition of acetoclastic and methanogenic bacteria, substrate and product mass transport limitation, sludge flotation, digester foaming, blockages of pipes and pumps, and clogging of gas collection and handling systems [4]. Of these operational concerns the inhibition of methane generation as a result of the degradation products of the lipids in FOG is one of the most common [7].

These challenges pose significant hurdles to the direct or co-digestion of GTW. As pilot studies have shown the conversion of the FOG component of GTW to biodiesel is feasible [8]. An alternative strategy, then, could be to separate and recover the lipid rich FOG portion of GTW for use as a feedstock for biodiesel production and to anaerobically treat the leftover high strength wastewater to produce methane gas. Although methane has many benefits,

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biodiesel is a "heavy" fuel that can be easily blended with diesel to support ship, rail, and truck transportation [9]. Biodiesel is also the only alternative fuel that can be blended (at low concentration) with petroleum fuels to operate on unmodified combustion engines [10]. Although many have promoted the production of biodiesel from dark fermentation of sugars [11], processed sugar must be harvested and purified from crops (i.e. sugar cane) which introduces sufficient costs to undermine its utility [12]. The production of biodiesel from microalgae harvested from solar driven production systems is challenged and a long way from reality [13,14]. Finally, biodiesel from oil seed crops challenges food production [15]. For these reasons it is worth considering the production of renewable biodiesel and not methane from the lipid rich FOG component of GTW. Lipid rich FOG presents a significant new feedstock market for biodiesel production; approximately 18.12 billion kilograms of GTW are generated annually in the United States, which contains ~1.812 billion kilograms per year of recoverable fats and oils that could produce ~1892.5 million liters of biodiesel per year [16].

A major biodiesel producer in Hawaii, Pacific Biodiesel, has recently commissioned a commercial scale operation that produces biodiesel from blended feedstocks including FOG high in free fatty acids (FFA's) with conversion efficiencies as high as 90%. In their approach the GTW is initially collected in tanker trucks and transported to a central processing plant where the FOG component is separated from the wastewater prior to its conversion to biodiesel. The separated high strength GTW wastewater is then discharged directly to the sewer system at a cost based on composition (i.e. the discharge fees are applied to the levels of biological oxygen demand (BOD_5) and total suspended solids (TSS) in addition to the volume of water discharged). To reduce these costs, it is proposed to treat the wastewater on-site through application of high rate anaerobic digestion to both reduce the wastewater COD and TSS content prior to its discharge to the sewer network while simultaneously producing methane gas. Although many studies to date have focused on either co-digestion of GTW with sewage sludge or the application of high rate anaerobic technologies to process FOG-like high lipid industrial wastes [4,17], there remains a paucity of commentary that addresses the anaerobic treatment of the high strength GTW wastewater component.

Anaerobic digestion of GTW wastewater faces significant challenge as components in food waste can be difficult to metabolize [18]. In this work we examine the approach of high rate anaerobic digestion using an integrated 3-phase high rate anaerobic digestion reactor system comprised of an initial continuously stirred hydrolysis tank reactor followed by two biochar filled column reactors connected in series. Corn cob biochar has a very high pore density and good pore size distribution [19,20], two qualities found to support growth of active biofilms that retain methanogenic archaea when processing wastewaters at relatively high organic loading rates (OLRs) and relatively short hydraulic retention times (HRTs) [21]. The aim of this work is to investigate the degree to which GTW wastewater can be processed readily at HRTs approaching 1 day with high COD reductions and methane yields (per unit COD reduced) that approach the theoretical limit (i.e. 0.35 m^3 kg COD_{red}) [22]. The energy content of biodiesel recovered from FOG (assuming a 90% conversion) plus the methane recovered from anaerobic digestion of GTW wastewater is also compared against the total energy content that could be recovered solely from anaerobic digestion of GTW.

2. Materials and methods

2.1. 3-Stage anaerobic digestion system

All experiments were conducted in a 3-phase anaerobic digester comprised of an initial 3 L continuously stirred hydrolysis mixing tank (HYD, 2 L working volume) followed by two identical 5 L column reactors (R1 and R2, each of 4 L working volume) connected in series (Fig. 1). Internal recycle was used to provide intermittent mixing within each column via pumping (Greylor Co. 12 V AC pump model PQM-1/115) reactor fluid removed from just below the surface and pumping it back into the bottom of the reactor. The system HRT was controlled by peristaltic pumping (Watson-Marlow model 323s) of feed into the HYD tank through silicone tubing (Cole–Parmer model Masterflex 94610-14). Flow rate from the HYD

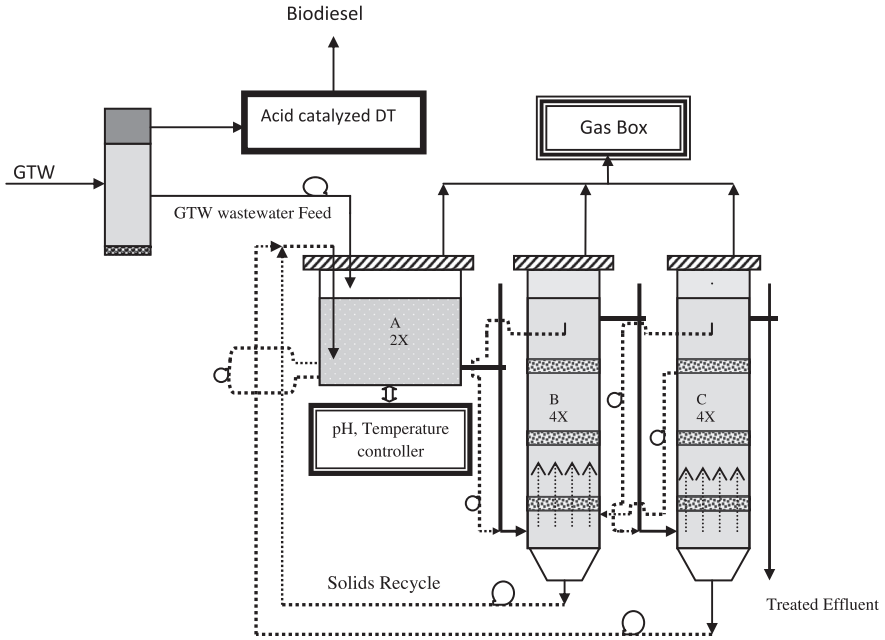

Fig. 1. Schematic of 3-stage packed bed up-flow column anaerobic digester reactor used in this study. Symbols: (A) Hydrolysis mixing tank (HYD); (B) Fixed film column reactor 1 (R1); (C) Fixed film column reactor 2 (R2).